

## Certain Peculiarities of Zr–Cr–N Coatings on Steel Blades of a Gas-Turbine Engine Compressor

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**Abstract**—The properties of compressor blades of a helicopter gas-turbine engine with an experimental ion-plasma coating Zr–Cr–N, are compared to those with Ti–Zr–N basic composition. It is shown that, due to the structural properties, the experimental coatings make the blades more corrosion-resistant, and mitigate the dependence of their residual properties on the amplitude and the temperature of the preliminary vibrotempering.

### INTRODUCTION

A complex problem of improving the corrosion and erosion resistance, as well as fatigue strength, of steel compressor blades of helicopter gas-turbine engines has long been known [1, 2]. An approach to its solution is to protect the blades by ion-plasma coatings based on Ti–N and Ti–Zr–N. In [3–6], we considered the performance characteristics of such compositions and concluded that anticorrosion properties of the coatings are insufficient. Based on the general concepts, one can expect the corrosion resistance of martensitic steel with nitride coatings to increase in response to forming metal interlayers enriched with chromium and zirconium in the coatings and eliminating titanium from the composition.

The purpose of this work is to study the behavior of the compressor steel blades (CTB) protected with coatings of the experimental Zr–Cr–N system, which were never used before.

### EXPERIMENTAL

We examined 3rd-stage rotor blades of a TV-2-117A engine's compressor. The blades were made of steel ЭИ961И [1–6].

Ion-plasma coatings 12 to 14  $\mu\text{m}$  thick were deposited at a "Bulat" unit at  $500 \pm 10^\circ\text{C}$  for 4 h, with a multistep variation of the partial pressures of Ar and  $\text{N}_2$ . As the basic composition, we chose ЭИ961 + (Ti, Zr)N with metal interlayers of  $\alpha$ -Ti and  $\alpha$ -Zr, which were sprayed from two titanium and one zirconium cathodes. The experimental coatings were applied under similar conditions from two zirconium and one chromium cathodes.

The tests for the gas–abrasive wear (GAW) were carried out on an experimental unit according to [3]. We determined the temperature dependence of specific wear ( $q$ ) in a range of 20 to  $350^\circ\text{C}$ , corrosion–erosion wear in a superheated steam with 3 wt % NaCl added

to the abrasive, and residual wear resistance ( $q_{\text{res}}$ ) at  $20^\circ\text{C}$  after a preliminary vibrotempering (PVT). The experimental error was  $\pm 0.1 \text{ mg/cm}^2 \text{ h}$ .

The preliminary vibrotempering of a blade fixed as a cantilever by the lock, was carried out on an electrodynamic testing unit GRW-TELTOW-61/450 for  $10^5$  cycles at a frequency of 50 Hz and an amplitude of free vibrations of the blade (A) of 0.5 to 2.5 mm. We designate the PVT at  $20^\circ\text{C}$  as "cold" and that at  $150^\circ\text{C}$  as "hot" (which virtually corresponds to a temperature range of the given stage of the compressor).

The tests for the fatigue strength were carried out at the same test unit under a resonance mode in a rigidly fixed cross-section at 2/3 of the blade's height at  $20^\circ\text{C}$  [4–6]. The gauge length of the tests was  $2 \times 10^6$  cycles, the interval of resonance-frequency range was 82–100 Hz. In addition to the initial strength ( $\sigma_{-1}$ ), the residual strength upon vibrotempering ( $\sigma_{-1 \text{ res}}$ ) was determined.

The corrosion tests were carried out in a G-4 type climatic chamber in vapors of a 3% NaCl aqueous solution at  $45^\circ\text{C}$  for 10 full days. We determined either the number of pits on a blade, or, when this number increased and pits merged together, the relative surface of damaged areas on the blade ( $S$ , %). We define a simple exposure of the blades in the initial state as "cold" corrosion (CC); tests with a 60-min heating at  $300^\circ\text{C}$  before each full-day cycle of exposure in the climatic chamber are called "hot" corrosion (HC).

X-ray diffraction analysis was accomplished by using a DRON-3,0 instrument with  $\text{CoK}_\alpha$  emission.

All the data shown in this work were obtained from testing 3–8 first category blades of the same batch.

### RESULTS AND DISCUSSION

X-ray diffraction analyses revealed main differences between experimental coatings and basic ones.

Figure 1 shows typical fragments of x-ray patterns and the most probable version of their interpretation. The existence of metal interlayers of  $\alpha$ -Ti,  $\alpha$ -Zr, and  $\alpha$ -Cr becomes more obvious upon the partial etching of nitride coatings in alkali [5]. Taking into account the results of detailed studies of basic coatings [3, 4], we managed to elucidate the structural properties of Zr-Cr-N coatings from their interference patterns. At least five of these features can be formulated as separate statements.

1. The presence of  $\langle 100 \rangle_{\text{ZrN}}$  grain orientation.
2. The presence of an interlayer of  $\alpha$ -Cr, which, probably, is epitaxially conjugated with the basic lattice in accordance with the "cube-in-cube" orientation [8] (grain orientations  $\langle 110 \rangle_{\text{Cr}}$  and  $\langle 110 \rangle_{\text{Fe}}$  are typical), and also of structurally free highly dispersed particles  $\text{Cr}_2\text{N}$ .
3. A substantial reduction of the relative intensity of ZrN reflexes and their adequate physical broadening. From our viewpoint, these reflexes are associated with additional dispersion of nano-dimension grains.
4. A noticeable decrease in the lattice parameter of ZrN from  $a = 0.451$  (basic composition) to  $a = 0.447$  nm. Even in the basic composition, the lattice parameter of ZrN is lower than the stoichiometric value due to the dissolution of titanium; in the experimental coating, an additional decrease in  $a_{\text{ZrN}}$  can be attributed to the dissolution of chromium atoms [9].
5. Revealing no ternary nitride compounds and intermetallic phases in the metal interlayer by x-ray diffraction analysis.

The factors listed affect correspondingly the complex of the composition's properties. For example, Fig. 2 shows the temperature dependence of the specific wear of unprotected and protected blades. It is evident that, up to  $\sim 330^\circ\text{C}$ , the experimental coatings enhance the gasoabrasive wear-resistance of blades by 10–25%, compared with basic coatings. Apparently, in this case, the determining factor is an additional dispersion of ZrN grains (similar to the results of [10]).

The points 4–6 in Fig. 2 also clearly demonstrate the advantage of the experimental coatings (compared with unprotected blades and those with basic coatings) under the erosion-corrosion attack of a superheated ( $150^\circ\text{C}$ ) steam and abrasive with an addition of NaCl, for a 60-min gauge length [3].

The tests for "cold" and "hot" corrosion in a climatic chamber demonstrated that the experimental Zr-Cr-N coatings much better protect martensitic steel ЭИ961 than basic Ti-Cr-N coatings do (table). Even those areas of CTB blades with a (Zr, Cr)N coating that suffered GAW by 80–85% exhibit a residual corrosion resistance close to the values shown in the column CC. Under conditions of "hot" corrosion, the above difference in the damage to worn coatings levels out. This fact indirectly suggests that the better corrosion resistance of Zr-Cr-N coatings is caused by electrochemi-

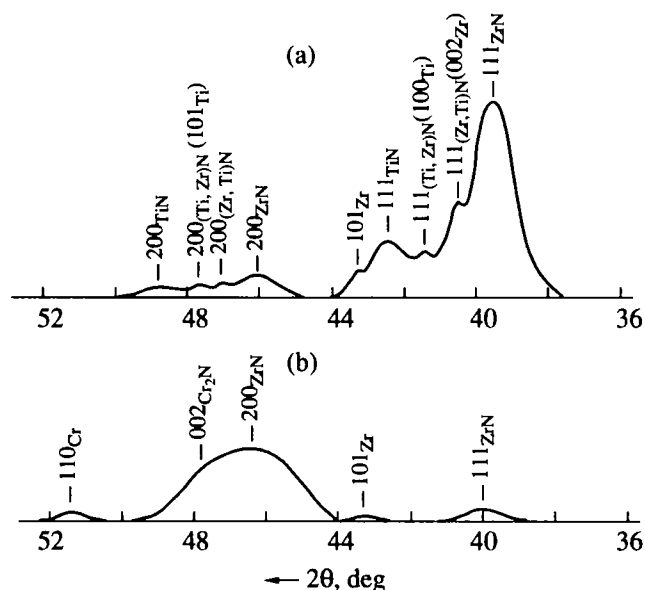


Fig. 1. Fragments of X-ray diffraction patterns of (a) basic and (b) experimental coatings.

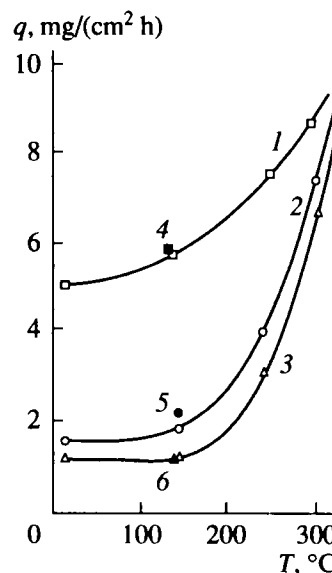


Fig. 2. Temperature dependence of specific wear of blades made of (1, 4) ЭИ961, (2, 5) ЭИ961 + (Ti, Zr)N, (3, 6) ЭИ961 + (Zr, Cr)N; (4–6) corrosion-erosion tests in the superheated steam with 3 vol % NaCl added to the abrasive.

cal interaction of these layers with martensitic substrate and nitride layer [7] rather than inherent anticorrosion properties of  $\alpha$ -Cr and  $\alpha$ -Zr layers.

Among the most important criteria of the operational reliability of CTB is also the dependence of their residual properties on the amplitude and temperature of PVT. In [6], we considered the total nonmonotonic effect of preliminarily vibrotempering the blades protected by nitride coatings on their residual properties.

The shape variation of the curves of residual wear resistance and fatigue-strength upon PVT (Fig. 3) is

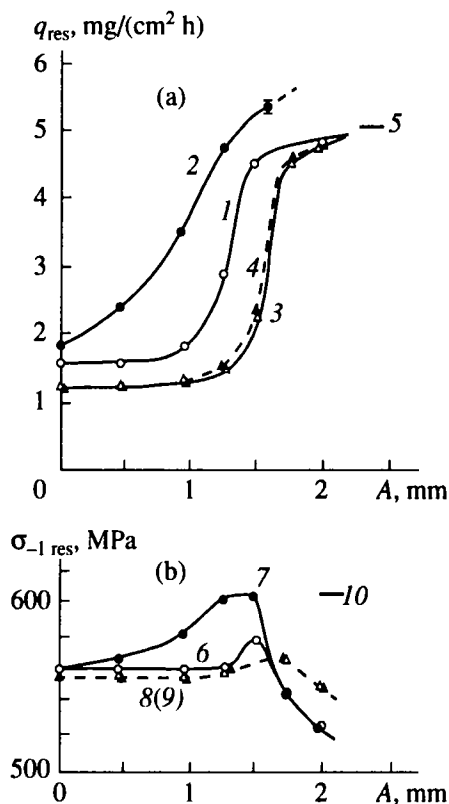


Fig. 3. Dependence of (a) residual wear and (b) fatigue strength of blades on the amplitude and temperature of their preliminary vibrotempering: (1, 2, 6, 7) ЭИ961 + (Ti, Zr)N, (3, 4, 8, 9) ЭИ961 + (Zr, Cr)N, (5, 10) ЭИ961, (1, 3, 6, 8) PVT at 20°C, (2, 4, 7, 9) PVT at 150°C.

best explained by the presence, in the experimental coating, of an interlayer of  $\alpha\text{-Cr}$  (which is conjugated epitaxially with the steel substrate) and by the grain orientation  $\langle 100 \rangle_{\text{ZrN}}$ . Note that we have already shown the essentiality of the  $\langle 100 \rangle_{\text{MeN}}$  grain orientation [4], as well as the presence of the layers epitaxial to the substrate [8], for combining sufficiently high wear resistance and fatigue limits of compressor blades with face-centered cubic nitride coatings.

In this study, the most important feature is not the fact that the aforementioned parameters more weakly

depend on the amplitude of free vibrations of experimental blade, but their practically complete independence of the temperature of PVT. The initial wear at  $A = 0$  in curve 2 (Fig. 3a) is associated with the simulated heating of blades at 150°C for 34 min (compare to Fig. 2).

As was mentioned above, similar effects were considered in [6] for the basic composition on ЭИ961 and BT8 alloys. In that work, it was shown (this is also confirmed by curve 2 in Fig. 3a, in which the experimental error interval widens and the wear of blades protected with a basic coating turns out to be more drastic than that of uncovered blades), that, after a "hot" PVT, the wear of steel articles with a (Ti, Zr)N coating includes the adhesion spalling of the coating and a decrease of their yield strength by about 10%.

Compressor turbine blades with experimental coatings reveal neither the effect of a decrease in  $\sigma_{0.2}$  nor the adhesion spalling even after the PVT at 220°C. The nonelastic interaction of the abrasive particles with the composition manifests itself only upon vibrotempering with an amplitude  $A = 3.0$  mm at 250°C.

It is also typical that the residual fatigue strength of experimental CTB never falls to the level of unprotected blades (see Fig. 3a), which once again proves that Zr-Cr-N coatings are bound to the substrate by a qualitatively different mechanism.

## CONCLUSIONS

Thus, we can conclude that the experimental ion-plasma (Zr, Cr)N coating on ЭИ961 steel differs from the basic (Ti, Zr)N coating by its grain orientation  $\langle 100 \rangle_{\text{ZrN}}$ , the possible epitaxial orientation of the  $\alpha\text{-Cr}$  interlayer to the martensitic substrate, and its fine-grain structure. Moreover, it substantially enhances the corrosion resistance of CTB, as was demonstrated by the results of three testing techniques;

increases their gasoabrasive wear resistance by 10–25% in the working temperature range;

reduces the deterioration of their wear resistance and fatigue strength with an increase in the amplitude

Corrosion damage (the number of pits or the relative damaged area of a blade,  $S$ , %) of steel CTBs with basic and experimental coatings

Number of sample	Coating	Exposure time at CC, days			Number of sample	Coating	Exposure time at HC, days		
		3	6	10			3	6	10
1	(TiZr)N	3	20	39	7	(TiZr)N	14	8%	11%
2	The same	5	22	26	8	The same	20	11%	14%
3	"	6	27	27	9	"	28	11%	13%
4	(ZrCr)N	0	2	2	10	(ZrCr)N	5	7	9
5	The same	0	5	6	11	"	2	7	10
6	"	1	2	4	12	"	0	3	4

of free vibrating of blade during the preliminary vibrotempering;

and prevents the adhesion spalling of the coating and a decrease in the yield strength of the blades upon "cold" and "hot" PVT.

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